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(54) AUTOMATIC CAPTURE OF DETAILED ANALYSIS INFORMATION FOR WEB APPLICATION OUTLIERS WITH VERY LOW OVERHEAD

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G06N 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G06N 5/00*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 11/34; G06F 11/36; G06F 9/50; G06Q 10/06
USPC 706/12
See application file for complete search history.

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Assistant Examiner — Michael Zidanic
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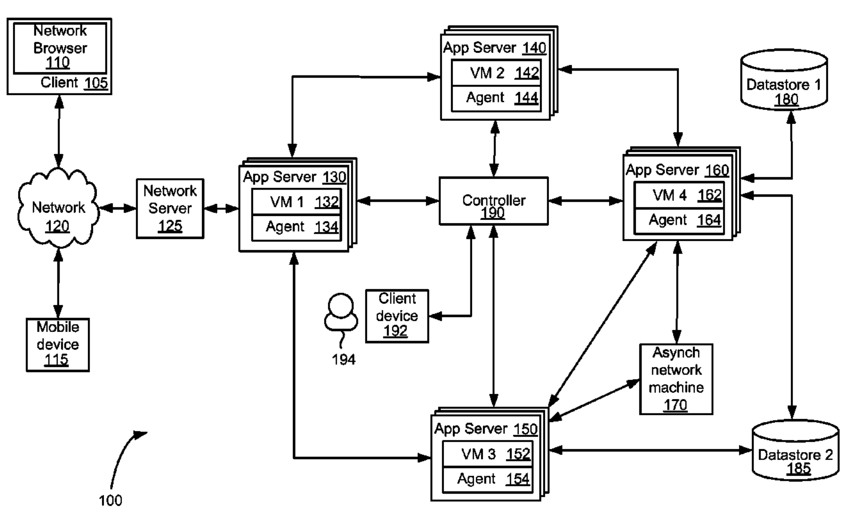
(57) **ABSTRACT**

A system monitors a network or web application provided by one or more distributed applications and provides data for each and every method instance in an efficient low-cost manner. The web application may be provided by one or more web services each implemented as a virtual machine or one or more applications implemented on a virtual machine. Agents may be installed on one or more servers at an application level, virtual machine level, or other level. The agent may identify one or more hot spot methods based on current or past performance, functionality, content, or business relevancy. Based on learning techniques, efficient monitoring, and resource management, the present system may capture data for and provide analysis information for outliers of a web application with very low overhead.

26 Claims, 10 Drawing Sheets



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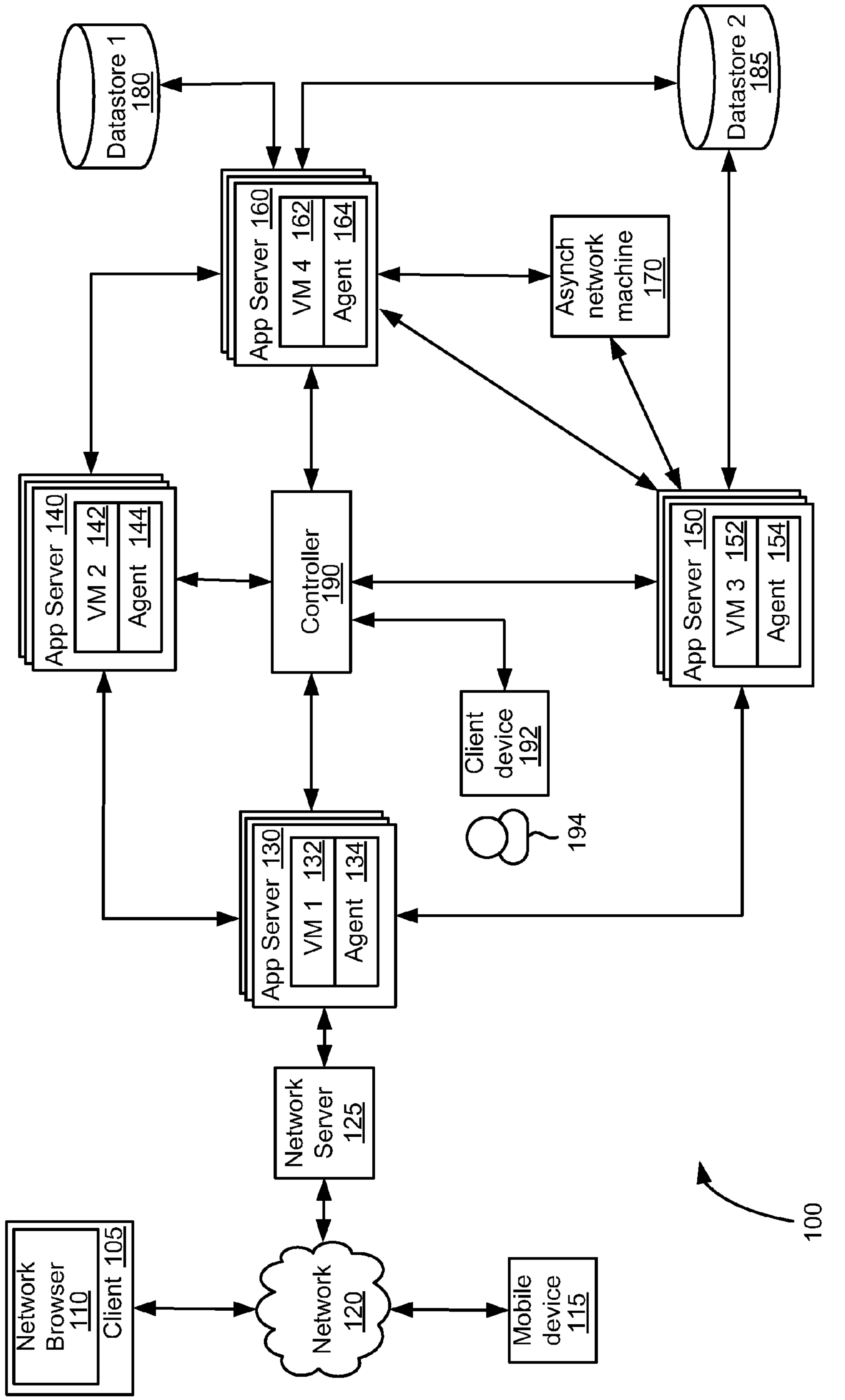

Datastore 1 180
Datastore 2 185
App Server 160
VM 4 162
Agent 164
Asynch network machine 170
App Server 140
VM 2 142
Agent 144
Controller 190
App Server 150
VM 3 152
Agent 154
Client device 192
194
App Server 130
VM 1 132
Agent 134
Network Server 125
Network Browser 110
Client 105
Network 120
Mobile device 115
100

FIGURE 1

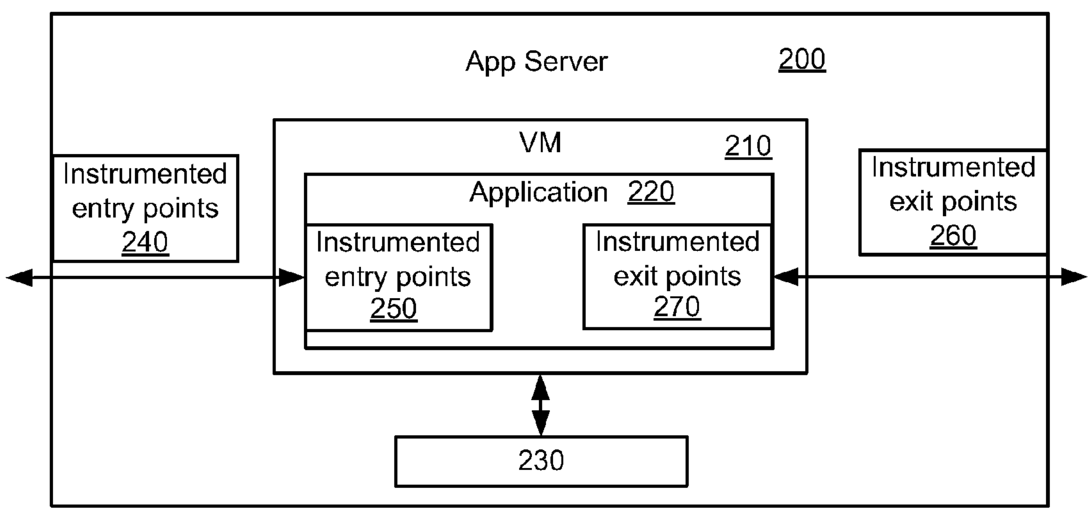

App Server 200
VM 210
Application 220
Instrumented entry points 240
Instrumented entry points 250
Instrumented exit points 270
Instrumented exit points 260
230

FIGURE 2

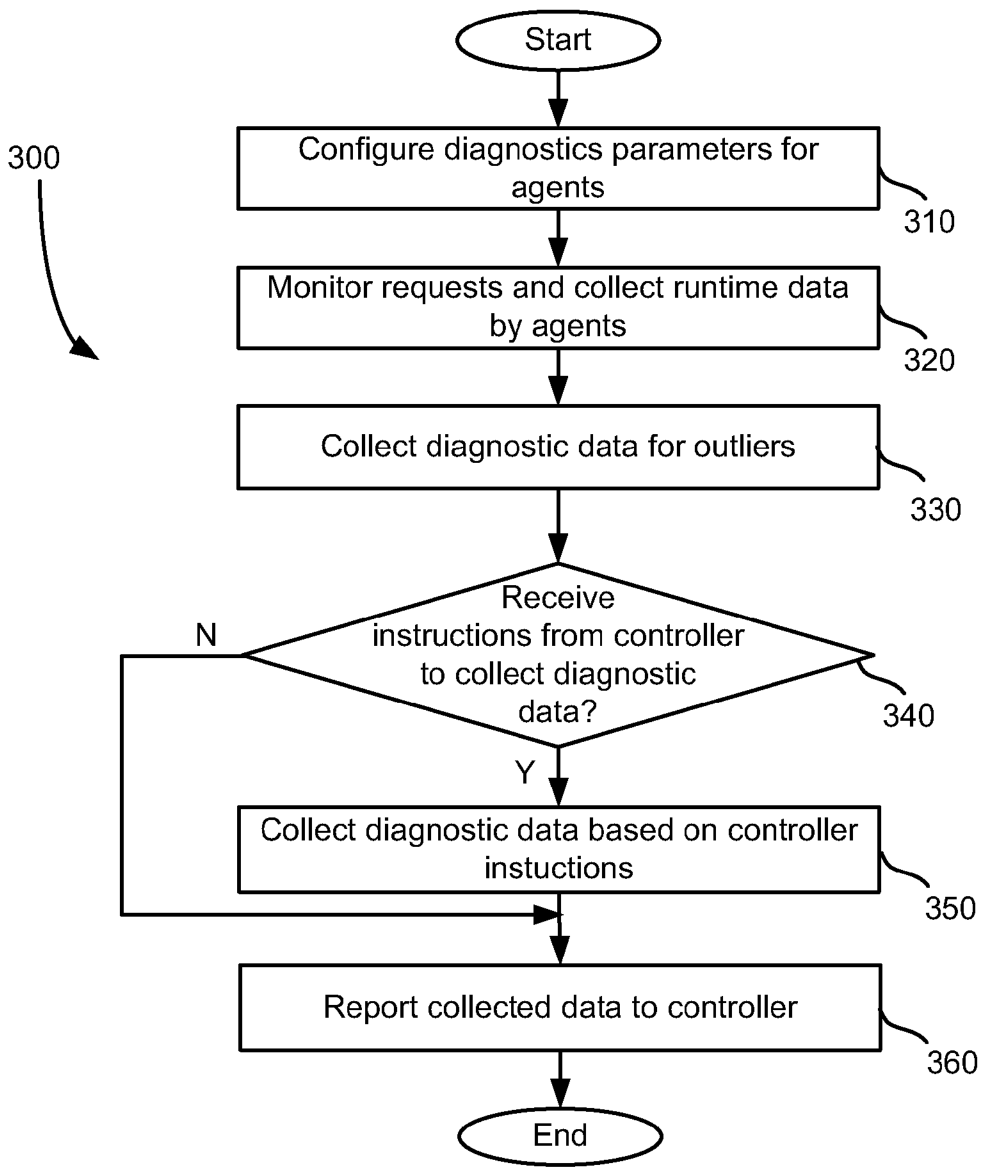

300
Start
Configure diagnostics parameters for agents
310
Monitor requests and collect runtime data by agents
320
Collect diagnostic data for outliers
330
Receive instructions from controller to collect diagnostic data?
340
N
Y
Collect diagnostic data based on controller instuctions
350
Report collected data to controller
360
End

FIGURE 3

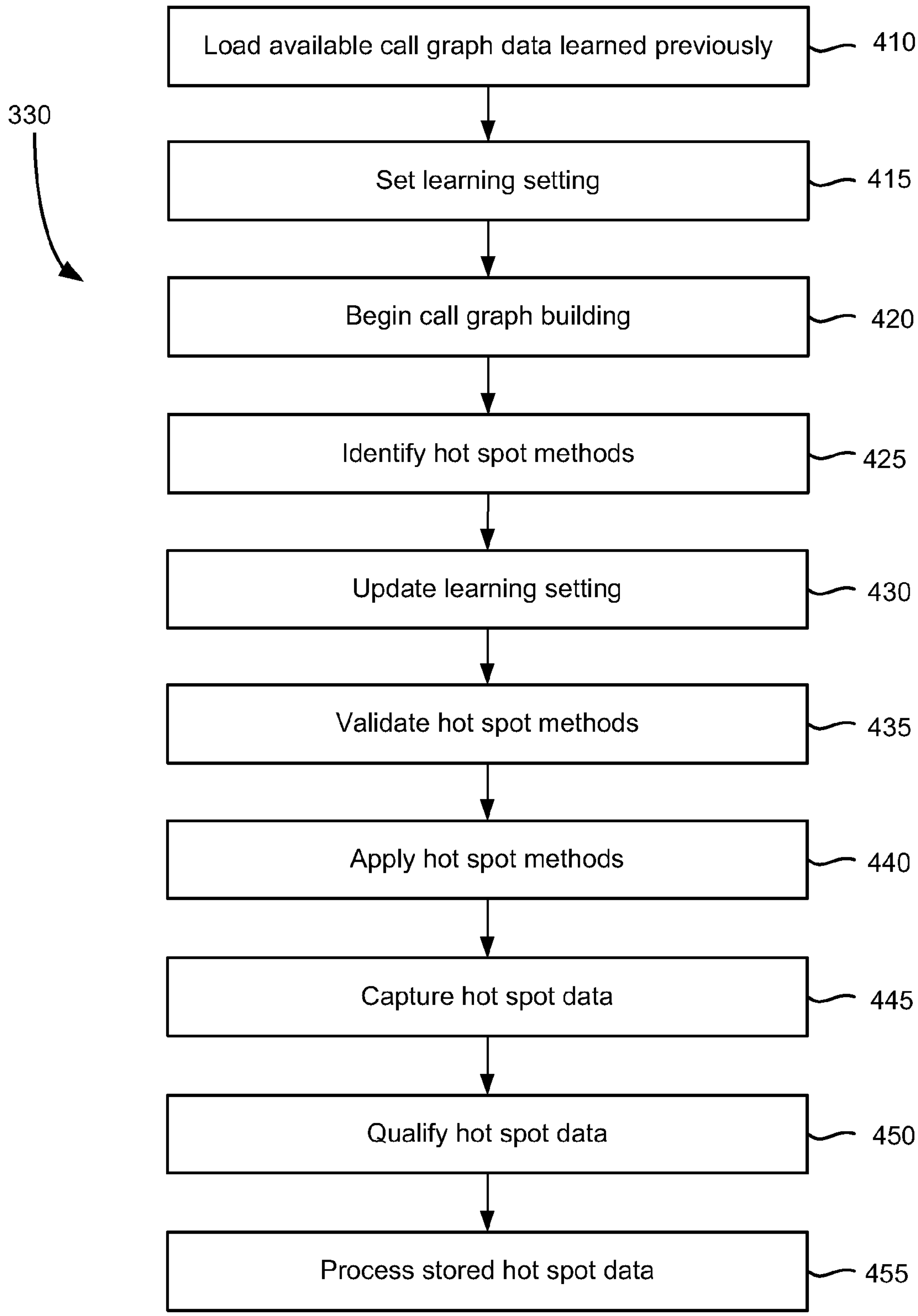

Load available call graph data learned previously
410
330
Set learning setting
415
Begin call graph building
420
Identify hot spot methods
425
Update learning setting
430
Validate hot spot methods
435
Apply hot spot methods
440
Capture hot spot data
445
Qualify hot spot data
450
Process stored hot spot data
455

FIGURE 4

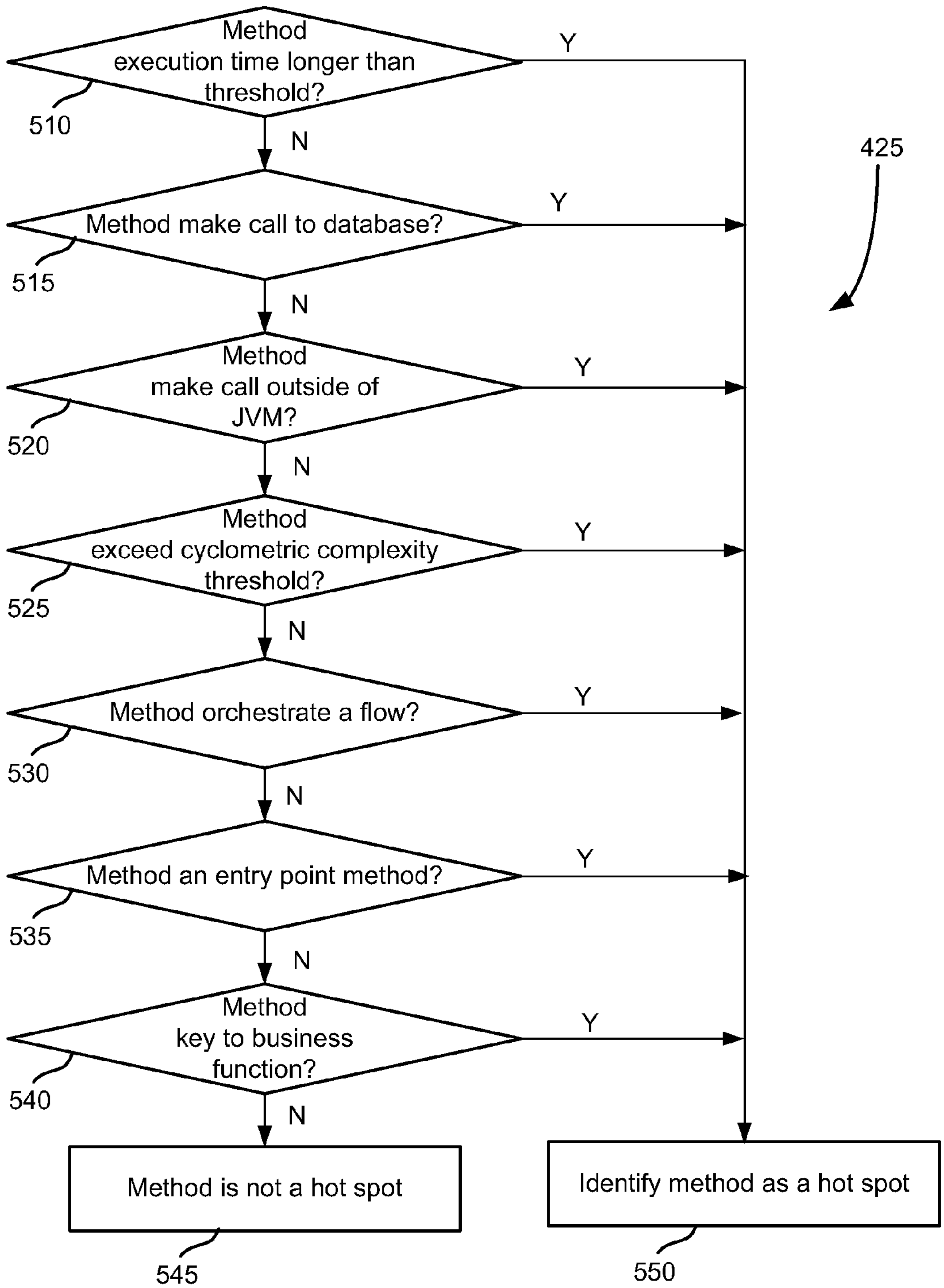
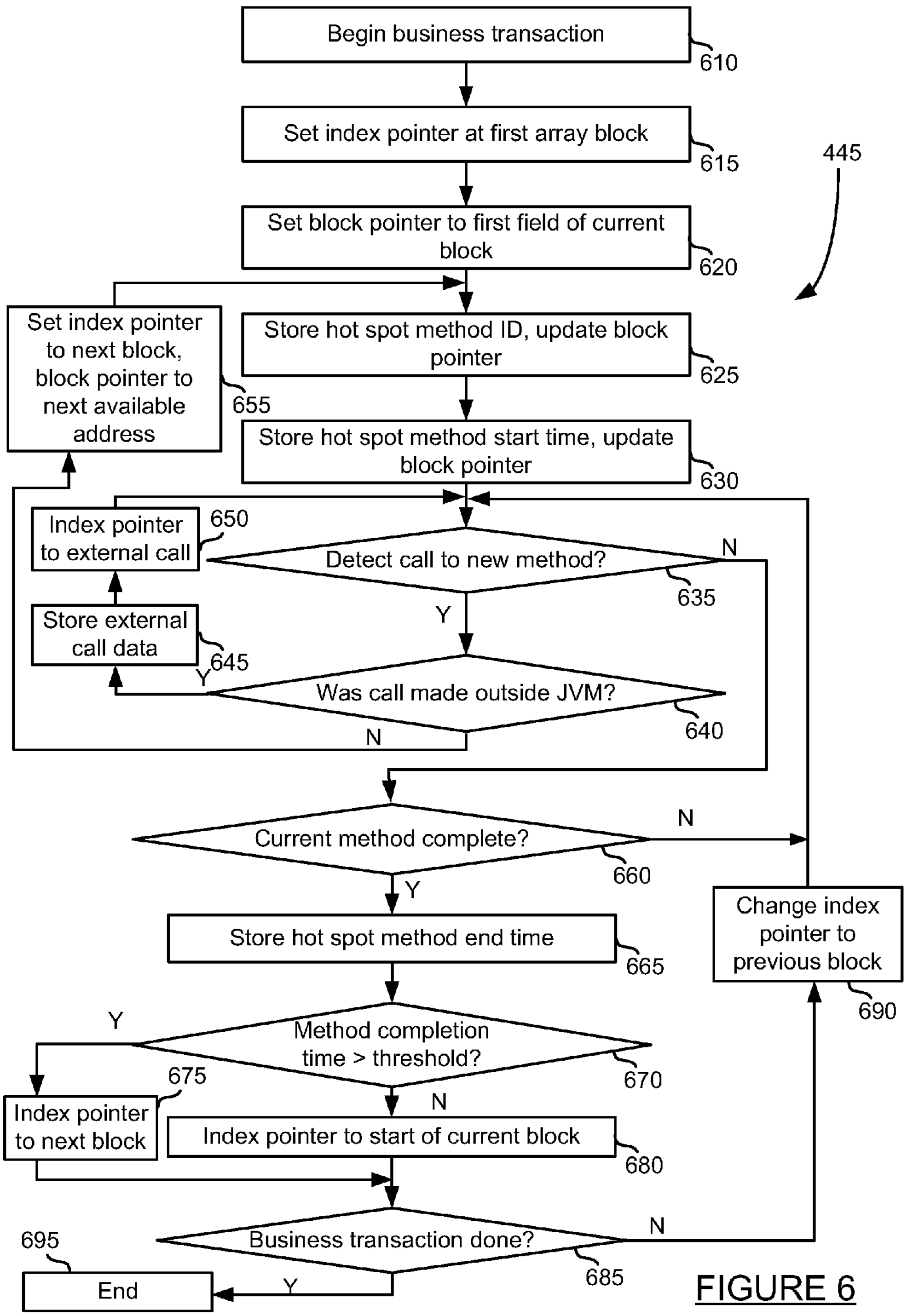

Method execution time longer than threshold?
Y
N
510
425
Method make call to database?
515
Method make call outside of JVM?
520
Method exceed cyclometric complexity threshold?
525
Method orchestrate a flow?
530
Method an entry point method?
535
Method key to business function?
540
Method is not a hot spot
545
Identify method as a hot spot
550

FIGURE 5



Begin business transaction
610
Set index pointer at first array block
615
445
Set block pointer to first field of current block
620
Set index pointer to next block, block pointer to next available address
655
Store hot spot method ID, update block pointer
625
Store hot spot method start time, update block pointer
630
Index pointer to external call
650
Detect call to new method?
N
635
Y
Store external call data
645
Y
Was call made outside JVM?
640
N
Current method complete?
N
660
Y
Store hot spot method end time
665
Change index pointer to previous block
690
Y
Method completion time > threshold?
670
675
N
Index pointer to next block
Index pointer to start of current block
680
Business transaction done?
N
695
685
End
Y

FIGURE 6

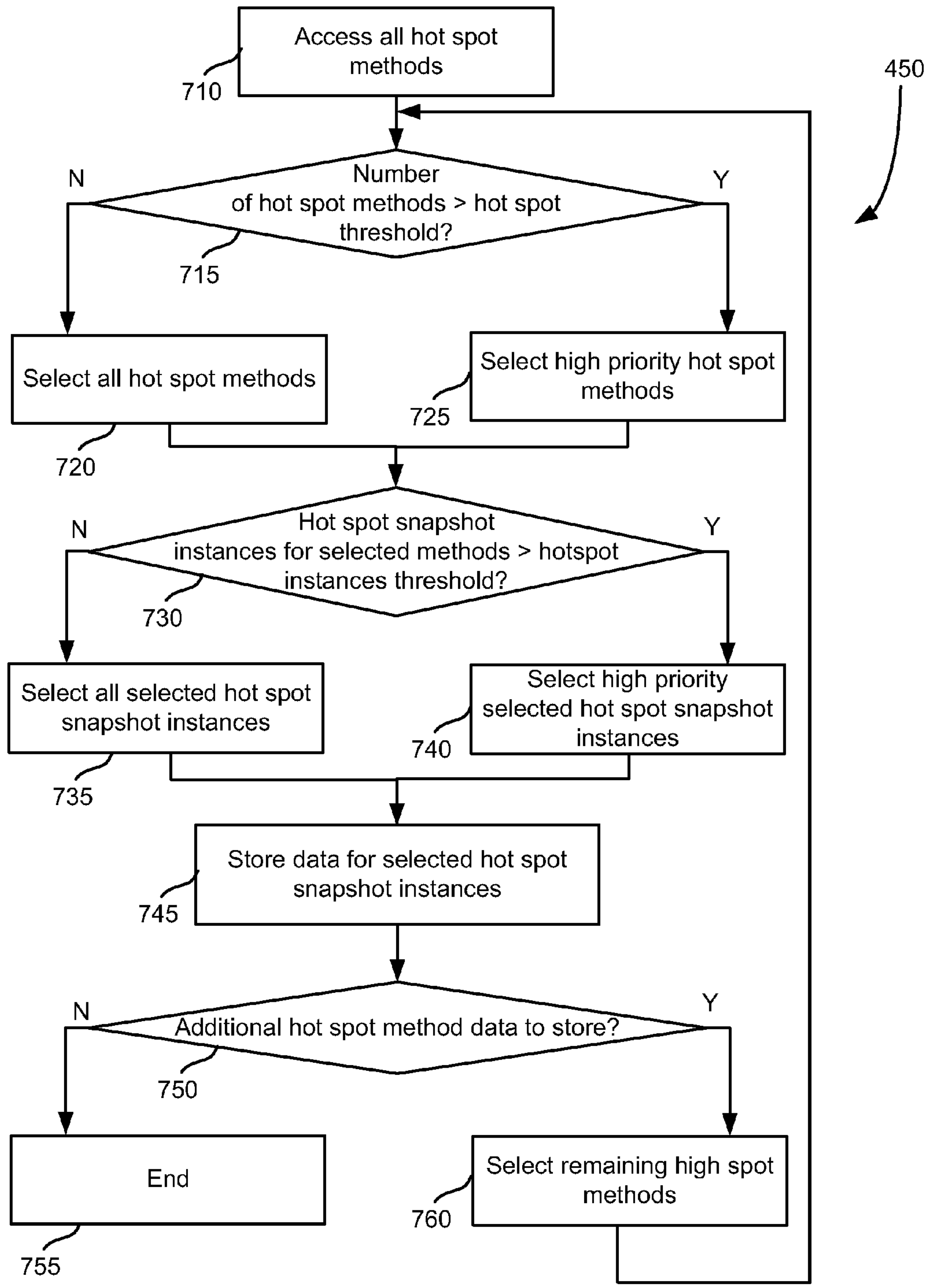

Access all hot spot methods
710
450
N
Y
Number of hot spot methods > hot spot threshold?
715
Select all hot spot methods
Select high priority hot spot methods
725
720
N
Y
Hot spot snapshot instances for selected methods > hotspot instances threshold?
730
Select all selected hot spot snapshot instances
Select high priority selected hot spot snapshot instances
740
735
Store data for selected hot spot snapshot instances
745
N
Y
Additional hot spot method data to store?
750
End
Select remaining high spot methods
760
755

FIGURE 7

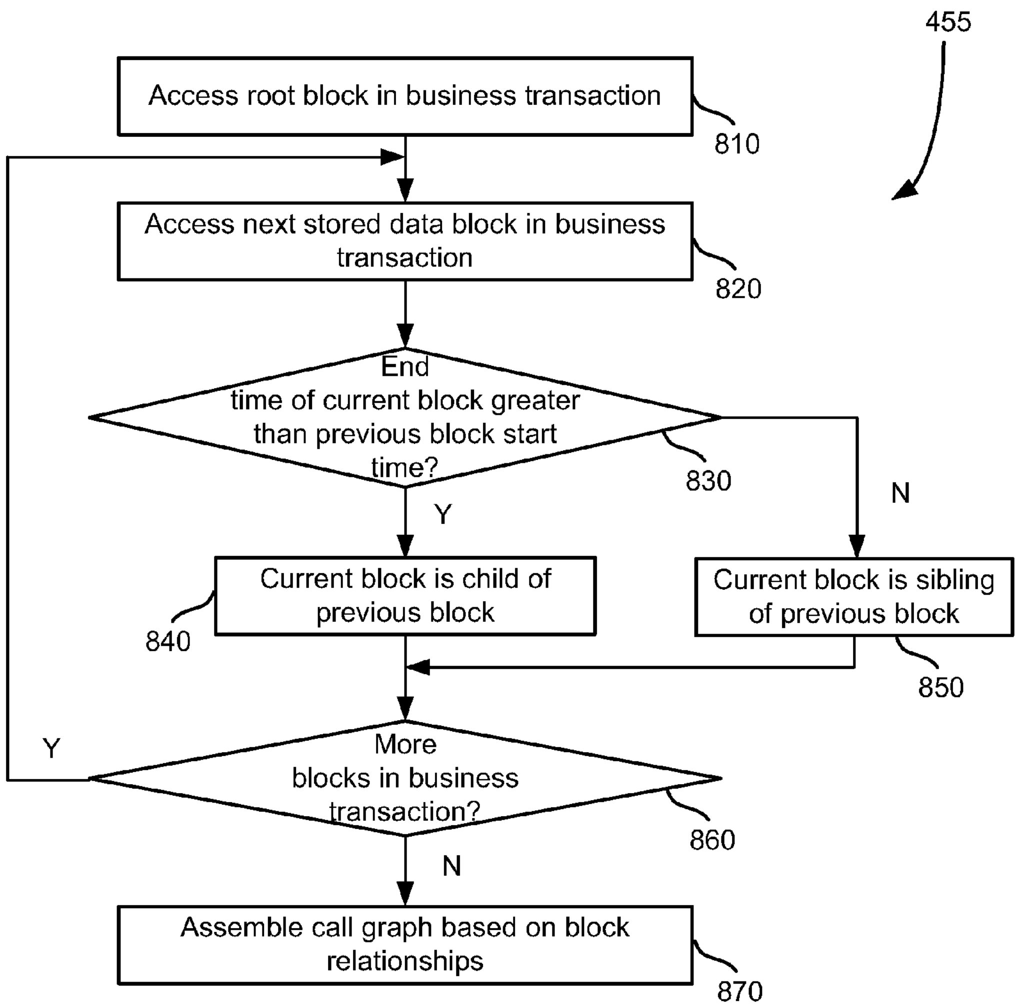

455
Access root block in business transaction
810
Access next stored data block in business transaction
820
End time of current block greater than previous block start time?
830
Y
N
Current block is child of previous block
840
Current block is sibling of previous block
850
More blocks in business transaction?
860
Y
N
Assemble call graph based on block relationships
870

FIGURE 8

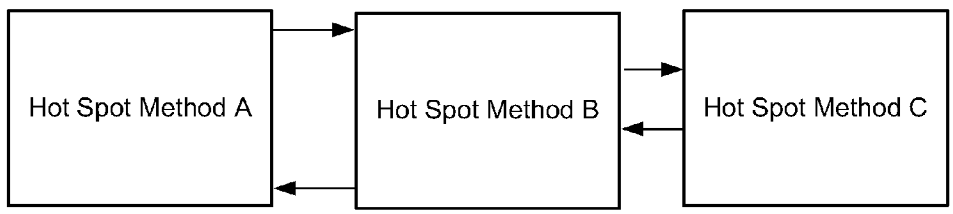


FIGURE 9A

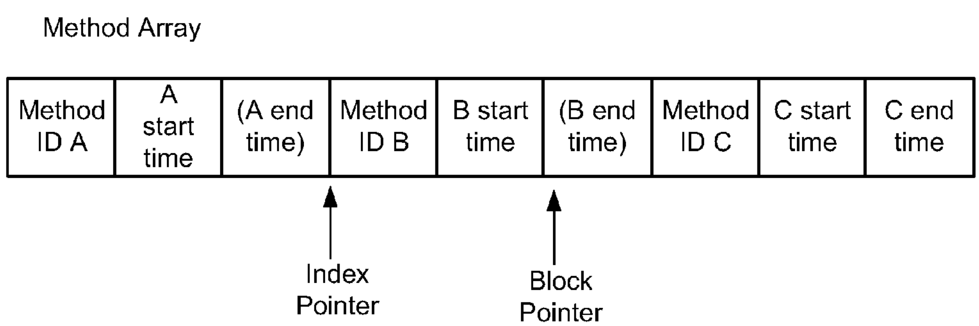


FIGURE 9B

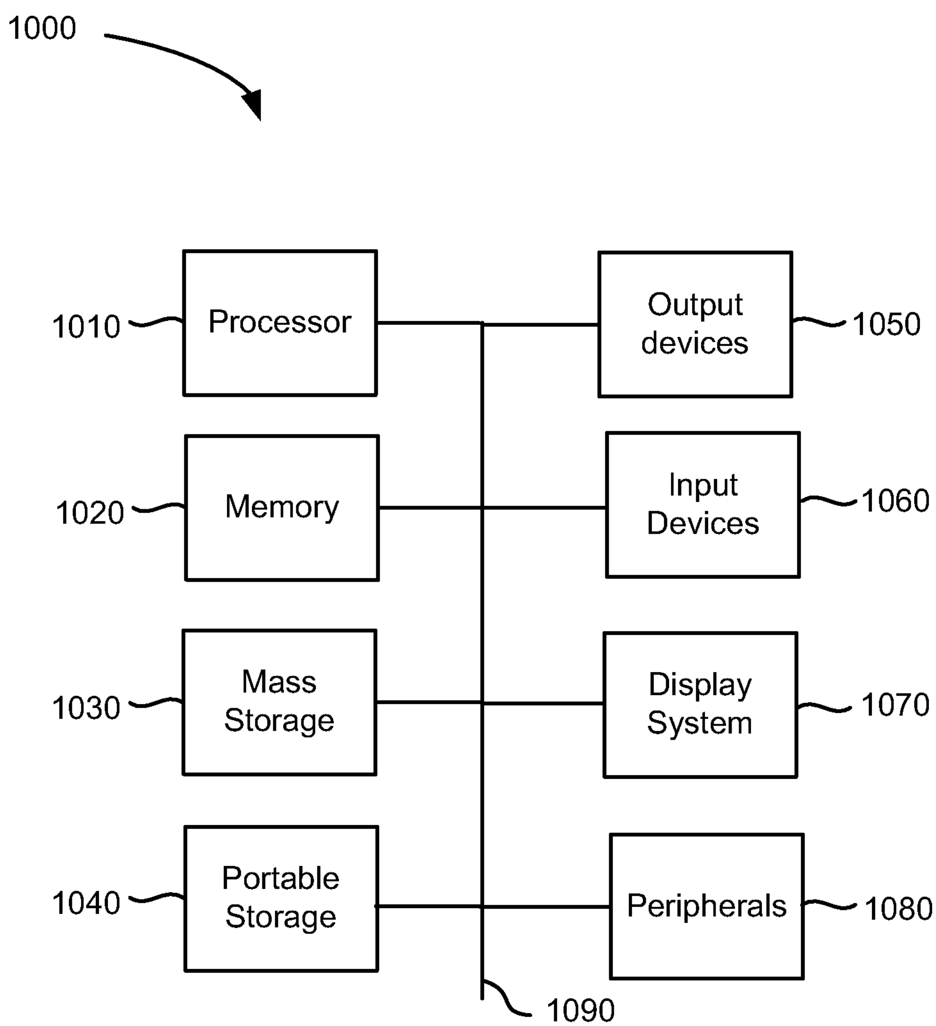

1000
1010
Processor
1020
Memory
1030
Mass Storage
1040
Portable Storage
Output devices
1050
Input Devices
1060
Display System
1070
Peripherals
1080
1090

Figure 10

AUTOMATIC CAPTURE OF DETAILED ANALYSIS INFORMATION FOR WEB APPLICATION OUTLIERS WITH VERY LOW OVERHEAD

BACKGROUND OF THE INVENTION

The World Wide Web has expanded to provide web services faster to consumers. Web services may be provided by a web application which uses one or more services to handle a transaction. The applications may be distributed over several machines, making the topology of the machines that provides the service more difficult to track and monitor.

Monitoring a web application helps to provide insight regarding bottle necks in communication, communication failures and other information regarding performance of the services the provide the web application. When a web application is distributed over several machines, tracking the performance of the web service can become impractical with large amounts of data collected from each machine.

When a distributed web application is not operating as expected, additional information regarding application performance can be used to evaluate the health of the application. Collecting the additional information can consume large amounts of resources and often requires significant time to determine how to collect the information.

It very difficult to collect information for specific methods that perform poorly. To collect and store information for each and every method of a web application would take up too many resources and degrade performance of the application. As a result, by the time a web application is detected to be performing poorly, it is too late to collect data regarding the performance of the instance that is performing poorly, and only subsequent methods can be monitored.

There is a need in the art for web service monitoring which may accurately and efficiently monitor the performance of distributed applications which provide a web service.

SUMMARY OF THE CLAIMED INVENTION

A system monitors a network or web application provided by one or more distributed applications and provides data for each and every method instance in an efficient low-cost manner. The web application may be provided by one or more web services each implemented as a virtual machine or one or more applications implemented on a virtual machine. Agents may be installed on one or more servers at an application level, virtual machine level, or other level. The agent may identify one or more hot spot methods based on current or past performance, functionality, content, or business relevancy. Based on learning techniques, efficient monitoring, and resource management, the present system may capture data for and provide analysis information for outliers of a web application with very low overhead.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an exemplary system for monitoring a distributed application.

FIG. **2** is a block diagram of an exemplary application server.

FIG. **3** is a flow chart of an exemplary method for performing a diagnostic session for a distributed web application transaction.

FIG. **4** is a flow chart of an exemplary method for tracking hot spot method data.

FIG. **5** is a flow chart of an exemplary method for identifying hot spot methods.

FIG. **6** is a flow chart of an exemplary method for capturing hot spot data.

FIG. **7** is a flow chart of an exemplary method for qualifying hot spot data.

FIG. **8** is a flow chart of an exemplary method for processing stored hot spot data.

FIG. **9**A is a block diagram of illustrating method calling hierarchy.

FIG. **9**B is a block diagram of a method array.

FIG. **10** is a block diagram of an exemplary system for implementing a computing device.

DETAILED DESCRIPTION

The present technology monitors a network or web application provided by one or more distributed applications and provides data for each and every method instance in an efficient low-cost manner. The web application may be provided by one or more web services each implemented as a virtual machine or one or more applications implemented on a virtual machine. Agents may be installed on one or more servers at an application level, virtual machine level, or other level. An agent may monitor a corresponding application (or virtual machine) and application communications. The agent may automatically identify one or more hot spot methods based on current or past performance, functionality, content, or business relevancy. The agent includes logic enabling it to automatically and dynamically learn the hot spot methods executing on a JVM. The hot spots are monitored, and data for the executed hot spot is kept or discarded based on the performance of the hot spot. Based on learning techniques, efficient monitoring, and resource management, the present system may capture data for and provide analysis information for outliers of a web application with very low overhead.

The hot spot monitoring may be performed by execution threads that manage method arrays of data. Each execution thread may manage one method array, and each method array may contain one block for each method that executes or is called by the executing method. Each block may include data used to analyze the method execution, such as for example a method ID, start time, end time. If a method called by an execution thread performs in a satisfactory manner, the data for the called method (method ID, start time, end time) is ignored and may be overwritten. If the method called by the execution thread (or the root method itself) does not perform in a satisfactory manner by for example exceeding a threshold time to complete, the data for the method is maintained and reported at the completion of the method. By monitoring method execution and call data in the thread header and ignoring data for methods that perform in a satisfactory manner, the present technology may monitor outliers for the duration of their execution in an efficient, low cost manner.

The present technology may perform a diagnostic session for an anomaly detected in the performance of a distributed web application. During the diagnostic session, detailed data may be collected for the operation of the distributed web application. The data may be processed to identify performance issues for a transaction. Detailed data for a distributed web application transaction may be collected by sampling one or more threads assigned to handle portions of the distributed business transaction. Data regarding the distributed transaction may be reported from one or more agents at an application or Java Virtual Machine (JVM) to one or more controllers. The data may be received and assembled by the one or more controllers into business transactions.

An anomaly in the performance of a distributed web transaction may be detected locally by an agent and centrally by a controller. An agent may locally detect an anomaly by processing collected runtime data for a request being processed by an application or JVM. The agent may determine baselines for request performance and compare the runtime data to the baselines to identify the anomaly. A controller may receive aggregated runtime data reported by the agents, process the runtime data, and determine an anomaly based on the processed runtime data that doesn't satisfy one or more parameters, thresholds or baselines.

The monitoring system may monitor distributed web applications across a variety of infrastructures. The system is easy to deploy and provides end-to-end business transaction visibility. The monitoring system may identify performance issues quickly and has a dynamical scaling capability across a monitored system. The present monitoring technology has a low footprint and may be used with cloud systems, virtual systems and physical infrastructures.

The present technology may monitor a distributed web application that performs one or more business transactions. A business transaction may be a set of tasks performed by one or more distributed web applications in the course of a service provide over a network. In an e-commerce service, a business transaction may be "add to cart" or "check-out" transactions performed by the distributed application.

Agents may communicate with code within virtual machine or an application. The code may detect when an application entry point is called and when an application exit point is called. An application entry point may include a call received by the application. An application exit point may include a call made by the application to another application, virtual machine, server, or some other entity. The code within the application may insert information into an outgoing call or request (exit point) and detect information contained in a received call or request (entry point). By monitoring incoming and outgoing calls and requests, and by monitoring the performance of a local application that processes the incoming and outgoing request, the present technology may determine the performance and structure of complicated and distributed business transactions.

FIG. **1** is a block diagram of an exemplary system for monitoring a distributed web application. The system of FIG. **1** may be used to implement a distributed web application and detect anomalies in the performance of the distributed web application. System **100** of FIG. **1** includes client device **105**, mobile device **115**, network **120**, network server **125**, application servers **130**, **140**, **150** and **160**, asynchronous network machine **170**, data stores **180** and **185**, and controller **190**.

Client device **105** may include network browser **110** and be implemented as a computing device, such as for example a laptop, desktop, workstation, or some other computing device. Network browser **110** may be a client application for viewing content provided by an application server, such as application server **130** via network server **125** over network **120**. Mobile device **115** is connected to network **120** and may be implemented as a portable device suitable for receiving content over a network, such as for example a mobile phone, smart phone, or other portable device. Both client device **105** and mobile device **115** may include hardware and/or software configured to access a web service provided by network server **125**.

Network **120** may facilitate communication of data between different servers, devices and machines. The network may be implemented as a private network, public network, intranet, the Internet, or a combination of these networks.

Network server **125** is connected to network **120** and may receive and process requests received over network **120**. Network server **125** may be implemented as one or more servers implementing a network service. When network **120** is the Internet, network server **125** maybe implemented as a web server.

Application server **130** communicates with network server **125**, application servers **140** and **150**, controller **190**. Application server **130** may also communicate with other machines and devices (not illustrated in FIG. **1**). Application server **130** may host an application or portions of a distributed application and include a virtual machine **132**, agent **134**, and other software modules. Application server **130** may be implemented as one server or multiple servers as illustrated in FIG. **1**.

Virtual machine **132** may be implemented by code running on one or more application servers. The code may implement computer programs, modules and data structures to implement a virtual machine mode for executing programs and applications. In some embodiments, more than one virtual machine **132** may execute on an application server **130**. A virtual machine may be implemented as a Java Virtual Machine (JVM). Virtual machine **132** may perform all or a portion of a business transaction performed by application servers comprising system **100**. A virtual machine may be considered one of several services that implement a web service.

Virtual machine **132** may be instrumented using byte code insertion, or byte code instrumentation, to modify the object code of the virtual machine. The instrumented object code may include code used to detect calls received by virtual machine **132**, calls sent by virtual machine **132**, and communicate with agent **134** during execution of an application on virtual machine **132**. Alternatively, other code may be byte code instrumented, such as code comprising an application which executes within virtual machine **132** or an application which may be executed on application server **130** and outside virtual machine **132**.

Agent **134** on application server **130** may be installed on application server **130** by instrumentation of object code, downloading the application to the server, or in some other manner. Agent **134** may be executed to monitor application server **130**, monitor virtual machine **132**, and communicate with byte instrumented code on application server **130**, virtual machine **132** or another application on application server **130**. Agent **134** may detect operations such as receiving calls and sending requests by application server **130** and virtual machine **132**. Agent **134** may receive data from instrumented code of the virtual machine **132**, process the data and transmit the data to controller **190**. Agent **134** may perform other operations related to monitoring virtual machine **132** and application server **130** as discussed herein. For example, agent **134** may identify other applications, share business transaction data, aggregate detected runtime data, and other operations.

Each of application servers **140**, **150** and **160** may include an application and an agent. Each application may run on the corresponding application server or a virtual machine. Each of virtual machines **142**, **152** and **162** on application servers **140-160** may operate similarly to virtual machine **132** and host one or more applications which perform at lease a portion of a distributed business transaction. Agents **144**, **154** and **164** may monitor the virtual machines **142-162**, collect and process data at runtime of the virtual machines, and communicate with controller **190**. The virtual machines **132**, **142**, **152** and **162** may communicate with each other as part of performing a distributed transaction. In particular each virtual machine may call any application or method of another virtual machine.

Controller **190** may control and manage monitoring of business transactions distributed over application servers **130-160**. Controller **190** may receive runtime data from each of agents **134-164**, associate portions of business transaction data, communicate with agents to configure collection of runtime data, and provide performance data and reporting through an interface. The interface may be viewed as a web-based interface viewable by mobile device **115**, client device **105**, or some other device. In some embodiments, a client device **192** may directly communicate with controller **190** to view an interface for monitoring data.

Asynchronous network machine **170** may engage in asynchronous communications with one or more application servers, such as application server **150** and **160**. For example, application server **150** may transmit several calls or messages to an asynchronous network machine. Rather than communicate back to application server **150**, the asynchronous network machine may process the messages and eventually provide a response, such as a processed message, to application server **160**. Because there is no return message from the asynchronous network machine to application server **150**, the communications between them are asynchronous.

Data stores **180** and **185** may each be accessed by application servers such as application server **150**. Data store **185** may also be accessed by application server **150**. Each of data stores **180** and **185** may store data, process data, and return queries received from an application server. Each of data stores **180** and **185** may or may not include an agent.

FIG. **2** is a block diagram of an exemplary application server **200**. The application server in FIG. **2** provides more information for each application server of system **100** in FIG. **1**. Application server **200** of FIG. **2** includes a virtual machine **210**, application **220** executing on the virtual machine, and agent **230**. Virtual machine **210** may be implemented by programs and/or hardware. For example, virtual machine **134** may be implemented as a JAVA virtual machine. Application **220** may execute on virtual machine **210** and may implement at least a portion of a distributed application performed by application servers **130-160**. Application server **200**, virtual machine **210** and agent **230** may be used to implement any application server, virtual machine and agent of a system such as that illustrated in FIG. **1**.

Application server **200** and application **220** can be instrumented via byte code instrumentation at exit and entry points. An entry point may be a method or module that accepts a call to application **220**, virtual machine **210**, or application server **200**. An exit point is a module or program that makes a call to another application or application server. As illustrated in FIG. **2**, an application server **200** can have byte code instrumented entry points **240** and byte code instrumented exit points **260**. Similarly, an application **220** can have byte code instrumentation entry points **250** and byte code instrumentation exit points **270**. For example, the exit points may include calls to JDBC, JMS, HTTP, SOAP, and RMI. Instrumented entry points may receive calls associated with these protocols as well.

Agent **230** may be one or more programs that receive information from an entry point or exit point. Agent **230** may process the received information, may retrieve, modify and remove information associated with a thread, may access, retrieve and modify information for a sent or received call, and may communicate with a controller **190**. Agent **230** may be implemented outside virtual machine **210**, within virtual machine **210**, and within application **220**, or a combination of these.

FIG. **3** is a flow chart of an exemplary method for performing a diagnostic session for a distributed web application transaction. The method of FIG. **3** may be performed to a web transaction that is performed over a distributed system, such as the system of FIG. **1**.

Diagnostic parameters may be configured for a controller and one or more agents at step **310**. The diagnostic parameters may be used to implement a diagnostic session conducted for a distributed web application business transaction. The parameters may be set by a user, an administrator, may be pre-set, or may be permanently configured.

Examples of diagnostic parameters that may be configured include the number of transactions to simultaneously track using diagnostic sessions, the time of a diagnostic session, a sampling rate for a thread, and a threshold percent of requests detected to run slow before triggering an anomaly. The number of transactions to simultaneously track using diagnostic sessions may indicate the number of diagnostic sessions that may be ongoing at any one time. For example, a parameter may indicate that only 10 different diagnostic sessions can be performed at any one time. The time of a diagnostic session may indicate the time for which a diagnostic session will collect detailed data for operation of a transaction, such as for example, five minutes. The sampling rate of a thread may be automatically set to a sampling rate to collect data from a thread call stack based on a detected change in value of the thread, may be manually configured, or otherwise set. The threshold percent of requests detected to run slow before triggering an anomaly may indicate a number of requests to be detected that run at less than a baseline threshold before triggering a diagnostic session. Diagnostic parameters may be set at either a controller level or an individual agent level, and may affect diagnostic tracking operation at both a controller and/or an agent.

Requests may be monitored and runtime data may be collected at step **320**. As requests are received by an application and/or JVM, the requests are associated with a business transaction by an agent residing on the application or JVM, and may be assigned a thread within a thread pool by the application or JVM itself. The business transaction is associated with the thread by adding business transaction information, such as a business transaction identifier, to the thread by an agent associated with the application or JVM that receives the request. The thread may be configured with additional monitoring parameter information associated with a business transaction. Monitoring information may be passed on to subsequent called applications and JVMs that perform portions of the distributed transaction as the request is monitored by the present technology.

Diagnostic data may be collected for outliers at step **330**. Outlier data may be collected for an entire business transaction. The system may learn about the methods performed on a JVM, identify hot spot methods to monitor, capture data for the identified hot spot methods, and process the hot spot data. Hot spot methods are monitored in a very efficient and low cost manner, creating very little overhead and using few resources on JVMs being monitored. Tracking hot spot methods as part of collecting diagnostic data for outliers is discussed in more detail below with respect to the method of FIG. **4**.

A determination is made as to whether instructions have been received from a controller to collect diagnostic data at step **350**. A diagnostic session may be triggered "centrally" by a controller based on runtime data received by the controller from one or more agents located throughout a distributed system being monitored. If a controller determines that an anomaly is associated with a business transaction, or portion of a business transaction for which data has been reported to the controller, the controller may trigger a diagnostic session and instruct one or more agents residing on applications or JVMs that handle the business transaction to conduct a diagnostic session for the distributed business transaction. Operation of a controller is discussed in more detail below with respect to the method of FIG. **9**.

If no instructions are received from a controller to collect diagnostic data, the method of FIG. **3** continues to step **370**. If instructions are received to collect diagnostic data from a controller, diagnostic data is collected based on the controller instructions at step **360**. The agent may collect data for the remainder of the current instance of a distributed application as well as subsequent instances of the request. Collecting diagnostic data based on instructions received by a controller is described below with respect to the method of FIG. **5**. Next, data collected by a particular agent is reported to a controller at step **370**. Each agent in a distributed system may aggregate collected data and send data to a controller. The data may include business transaction name information, call chain information, the sequence of a distributed transaction, and other data, including diagnostic data collected as part of a diagnostic session involving one or more agents.

FIG. **4** is a flow chart of an exemplary method for tracking hot spot method data. The method of FIG. **4** provides more detail for step **330** of the method of FIG. **3**. Each step of FIG. **4** may be performed automatically by an agent (such as that illustrated in FIG. **1**) and/or other modules. Available call graph data learned previously may be loaded by an agent at the JVM at step **410**. In some embodiments, the agent may monitor one or more business transactions occurring at JVM to determine the methods and relationships between methods that make up the business transaction. As the business transaction methods are learned, they may be stored. When an agent beings monitoring hot spot methods at a later time, the learned methods and method relationships may be pre-loaded to prevent having to re-learn the business transaction(s) methods and method relationships again.

A learning setting may be set at step **415**. The learning setting may indicate for how long an agent will attempt to learn the different methods of a business transaction, how many methods the agent will attempt to identify, and other parameters of determining a call graph for one or more business transactions. Learning settings may include time, preferred business transactions, maximum number of business transactions, length of time to hibernate between learning sessions, and other parameters. When in "learning mode", an agent monitoring a JVM may identify each new method called during a learning period, and relationships of each method with any other method. When in "hibernate mode", an agent may not identify new methods or method relationships.

Learning of business transaction methods and method relationships may be ongoing. Though learning settings are set at step **415**, the settings may be changed at any time. Moreover, learning may occur as a continuous loop. Learning and hibernation may alternate based on time periods, rate of new methods learned, and other factors. For example, an agent may learn for five minutes upon execution of a JVM application, then hibernate for five minutes, and then "learn" methods and method relationships for another five minutes. In some embodiments, an agent may "learn" until no new methods are identified for a period of thirty seconds, and then hibernate for five minutes.

A call graph may be built at step **420**. After learning settings are initially set, an agent may monitor a JVM and build a call graph from the learned data. In some embodiments, the call graph may be built from the pre-loaded call graph data, method data observed while monitoring, or both. A call graph may indicate a root method of a business transaction, as well as each method called as part of the completion of the root method. Examples of call graphs are discussed in U.S. patent application Ser. No. 12/878,919, titled "Monitoring Distributed Web Application Transactions", filed on Sep. 9, 2010, and U.S. patent application Ser. No. 13/189,360, titled "Automatic Capture of Diagnostic Data Based on Transaction Behavior Learning", filed on Jul. 22, 2011, the disclosures of which are each incorporated herein by reference.

Hot spot methods are identified at step **425**. Hot spot methods are methods identified as being subject to monitoring. For example, a method may be identified as a hot spot method based on calls the method makes, complexity, or the method's performance. Identifying hot spot methods is discussed in more detail with respect to the method of FIG. **5**.

Learning settings may be updated at step **430**. As discussed above, learning may be an ongoing process. As part of the ongoing process, learning settings may be adjusted over time. For example, after hot spot methods are identified, an agent at a JVM may update learning settings to adjust the time spent learning new methods of a call graph. Though updating learning settings is illustrated at step **430**, learning settings may be updated at any time throughout the method of FIG. **4**.

Hot spot methods may be validated at step **435**. Validation of hot spot methods may include monitoring a JVM to confirm that the identified hot spot methods should indeed be labeled hot spot methods. For example, the validation may confirm that a method typically takes longer than a threshold time period to complete, that a method places a call to an outside database, or another condition typically occurs for each method that was identified as a hot spot method at step **425**.

Hot spot methods are applied at step **440**. Applying hot spot methods may include instrumenting the byte code of each method to store the start time and end time of the method. The instrumentation may also include a location reference within a method array for storing data, such as an end time for the method that is instrumented. An exemplary pseudo code for the instrumentation is shown below:

```
{
Start.onMethodBegin
  (Original method code)
  (Original method code)
  . . .
  (Original method code)
OnMethodEnd (9, A, B)
}
```

The original code of a hot spot method is instrumented such that when the method is called, the method ID and the start time of the method is written to the execution thread header for the thread executing the method. When the method ends, the end time is written to the thread header. The method ID, start time and end time may be written to a method array that is maintained in the execution thread.

Hot spot data may be captured at step **445**. Capturing hot spot data may include monitoring executing hot spot methods, tracking calls to additional methods and external machines, and keeping data that is relevant to outliers. Data that is not relevant to outliers, such as data for methods that perform well, may not be kept. Capturing hot spot data is discussed in more detail below with respect to FIG. **6**.

Hot spot data may be qualified at step **450**. Qualifying hot spot data may include determining which data to store and what data to not store. Qualifying hot spot data is discussed in more detail below with respect to FIG. **7**.

Hot spot data may be processed at step **455**. Processing of hot spot data may include building a call graph and presenting call graph information to a user. The call graph data may be presented as a graphical interface or in some other form. The call graph may be constructed from captured hot spot data which is stored until the call graph is requested by a user. Processing hot spot data is discussed in more detail below with respect to the method of FIG. **8**.

FIG. **5** is a flow chart of an exemplary method for identifying hot spot methods. The method of FIG. **5** provides more detail for step **425** of the method of FIG. **4**. A determination is made as to whether the execution time of the method was longer than a threshold. The threshold may be a preset setting or may be learned over time (e.g., as an average of previous method execution times). If the method execution time is longer than the execution time threshold, the method is identified as a hot spot at step **550**. If the method does not execute for a time longer than the execution threshold, the method continues to step **515**.

A determination is made as to whether the method made a call to a database at step **515**. In some embodiments, a method that makes a call to a specific application server, such as a database, may be identified as a hot spot method. If the method does not make a call to a database, the method may continue to step **520**. If the method does make a call to a database, the method is identified as a hot spot at step **550**.

At step **520**, a method is identified as a hot spot method (step **550**) if the method makes a call to an external JVM. If the method does not make a call to an external JVM, the method continues to step **525**.

At step **525**, a method may be identified as a hot spot method if the method exceeds a cyclometric complexity threshold. A cyclometric complexity threshold is one measure for expressing the complexity of a method. Thresholds relating to other measures of method complexity may also be used in place of, or in addition to, cyclometric complexity. If the method cyclometric complexity exceeds a cyclometric complexity threshold, the method is identified as a hot spot at step **550**. Otherwise, the method of FIG. **5** continues to step **530**.

A determination is made as to whether the method orchestrates a flow at step **530**. A method may orchestrate a flow if the method makes calls to one or more other methods, which in turn may make calls to one or more additional methods, and so forth. In various embodiments, the root method may be determined to "orchestrate" a flow if a at least a threshold number of children and grandchildren methods are called directly or indirectly from the root method. If the method orchestrates a flow, the method is identified as a hot spot at step **550**. Otherwise, the method continues to step **535**.

A method may be identified as a hot spot method if is determined to be an entry point method for the JVM at step **535**. If the hot spot method is not an entry point method, a determination is made as to whether the method is important to a business function at step **540**. For example, for an e-commerce site, a method that processes credit card information may be considered a key business function and, therefore, a hot spot method. If the method does not satisfy any condition described in steps **510-540**, the method is determined to not be a hot spot at step **545**. If the method satisfies any condition described in steps **510-540**, the method is identified as a hot spot at step **550**.

FIG. **6** is a flow chart of an exemplary method for capturing hot spot data. The method of FIG. **6** provides more detail for step **445** of the method of FIG. **4**. The method of FIG. **6** uses pointers and a method array stored in an execution thread header to track data for hot spot methods in a low cost manner.

A business transaction begins at step **610**. An index pointer is set to the first array of a block within the method array at step **615**. The array includes a block for each method called during execution of the root node of the method, with the first block associated with the root method. A block pointer is set to the first filed of the current block at step **620**. A hot spot method ID associated with the currently executing method is stored at the current block and field within the method array at step **625**, and the block pointer value is updated to point to the next field in the array. The hot spot method start time is then stored at the current block and field within the method array at step **630**, and the block pointer value is updated to point to the next field in the array.

The performance of a method may be determined by execution time or response time. The execution time is determined from the difference of the start time and the end time of the method's execution. The time may be taken from one of several different times, including but not limited to the JVM clock, a server clock, a block clock, or other clock time.

A determination is made as to whether a call to a new method is detected at step **635**. During execution of the current method, the method may call a new method to perform some function. If a call to a new method is not detected at step **635**, the method continues to step **660**.

If a call to a new method is detected at step **635**, a determination is made as to whether the call was made to an outside JVM at step **640**. If the call is made to an outside JVM, external call data is stored for the call at step **645** and the index pointer is set to the external call at step **650**. The method then continues to step **635**. If the call is not made to an external JVM, the index pointer is set to the next available block, the block pointer is set to the next available address, and the method continues to step **625**.

External call data may be stored in one of several formats, including a list or table format. For example, a table of external calls may be stored as a list of the external methods called and an identifier of the method that called the external call. The identifier may by a method array location corresponding to the method ID, a reference to the block associated with the method (i.e., block **1** corresponding to a root node method), or other identifier. If data for the method is eventually stored, the list (or table) of external call information is stored with the method array data.

A determination is made as to whether the current method is complete at step **660**. If the current method is still executing, the method returns to step **635**. When execution of the current method has completed, the hot spot method end time is written to the method array in the execution thread header at step **665**. In some embodiments, the end time is written to an address location specified by the instrumented code.

A determination is then made as to whether the method completion time is greater than a threshold value at step **670**. The threshold may be a pre-set value or learned over time for the particular method, class of method, business transaction, or related business transactions. In various embodiments, the threshold time may be 10 ms, 15 ms, 20 ms, or some other value. If the method execution time was greater than the threshold value, the index pointer is set to the next block (or next available block). By setting the index pointer to the next block location, the data for the method which just ended is saved. IF the method execution time is less than the threshold value, the index pointer is set to the start of the current block.

By setting the index pointer to the start of the current block, the data for the current block will be overwritten (and not saved).

A determination is then made as to whether the current business transaction has completed with the end of the current method. If the business transaction is complete, the method ends at step **695**. If the business transaction is not complete, the index pointer is set to the previous block and the method continues to step **635**.

FIG. **7** is a flow chart of an exemplary method for qualifying hot spot data. The method of FIG. **7** provides more detail for step **450** of the method of FIG. **4**. Hot spot methods are accessed at step **710**. A determination is then made as to whether the number of hot spot methods is greater than a hot spot threshold at step **715**. The hot spot threshold may be based on several factors, including the number of available threads that are available for storing data. If the number of methods is greater than the threshold, a set of high priority hot spots are selected at step **725** and the method continues to step **730**. Methods of high priority may be those that satisfy several conditions described with respect to the method of FIG. **5**. For example, a method that executes slower than a threshold time and calls an external JVM may have a higher priority than a method that executes slower than a threshold time and does not call an external JVM. If the number of hot spots does not exceed a hot spot threshold, all hot spots are selected at step **720** and the method continues to step **730**.

A determination is made as to whether the number of hot spot snapshot instances is greater than a hot spot instance threshold at step **730**. A hot spot snapshot instance is a set of data resulting from the execution of a method instance. An instance of a method may be executed one or more times. A hot spot snapshot instance is a "snapshot" or set of the data generated from the execution of the instance. The hot spot instance threshold may be selected to avoid an undesirable level of overhead or resource usage at the JVM. For example, a hot spot instance threshold of 20 may be used if it is determined that storing hot spot data for twenty method instances does not cause a noticeable performance delay in the JVM. If the number of hot spot snapshot instances is not greater than the hot spot instance threshold, all snapshot instances are selected at step **735** and the method continues to step **745**. If the number of hot spot snapshot instances is greater than the hot spot instance threshold, a number of high priority hot spot snapshot instances of the selected hot spot methods are selected at step **740** and the method continues to step **745**. Hot spot snapshot instances may be designated as high priority based on one or more factors, including for example the length of execution time, the number of conditions discussed with reference to FIG. **5** which are violated by the method class, and other factors.

Data for the selected hot spot snapshot instances is stored at step **745**. The data may be stored by an agent locally to the agent's JVM until data is reported to a controller. The stored data may include the method array written to the thread header during execution of the methods as well as external call data, such as a list of external calls made by the methods being monitored.

A determination is then made as to whether there is additional hot spot method data to store at step **750**. If there is no further hot spot method data, the method ends at step **755**. If there is additional hot spot method data, the remaining hot spot methods are selected and the method continues to step **715**.

FIG. **8** is a flow chart of an exemplary method for processing stored hot spot data. The method of FIG. **8** provides more detail for step **455** of the method of FIG. **4**. A root block is accessed in a business transaction at step **810**. The next stored data block in the business transaction is accessed at step **820**. A determination is then made as to whether the end time of the current block is greater than the start time of the previous block at step **830**. The determination is designed to indicate whether the current block is a sibling or a child of the previous block. Other comparisons may be made to determine the relationship between the methods associated with the current block and the previous block. If the current block end time is not greater than the start time of the previous block, the current block is determined to be a sibling of the previous block (step **850**) and the method continues to step **860**. If the current block end time is greater than the start time of the previous block, the current block is determined to be a child of the previous block (step **840**) and the method continues to step **860**.

A determination is made as to whether more blocks exist in the method array to process at step **860**. If more blocks exist, the method continues to step **820**. If the blocks don't exist, the call graph is assembled based on block relationships and provided to a user at step **870**.

FIG. **9**A is a block diagram of illustrating method calling hierarchy. As illustrated in FIG. **9**A, methods A, B and C are identified as hot spot methods. Hot spot A makes a call to method B, and method B may call method C. Method C is a child of method B, and method B is a child of method A.

FIG. **9**B is a block diagram of a method array. The array of FIG. **9**B illustrates blocks pertaining to methods A, B and C of FIG. **9**A. Each block includes a method ID, start time, and end time field for the method corresponding to the block. An index pointer is set to the currently executing block location within the array, and the block pointer is set to a location within the current block.

FIG. **10** illustrates an exemplary computing system **1000** that may be used to implement a computing device for use with the present technology. System **1000** of FIG. **10** may be implemented in the contexts of the likes of clients **105-115**, network server **125**, application servers **130-160**, machine **170**, datastores **180-185**, and controller **190**. The computing system **1000** of FIG. **10** includes one or more processors **1010** and memory **1010**. Main memory **1010** stores, in part, instructions and data for execution by processor **1010**. Main memory **1010** can store the executable code when in operation. The system **1000** of FIG. **10** further includes a mass storage device **1030**, portable storage medium drive(s) **1040**, output devices **1050**, user input devices **1060**, a graphics display **1070**, and peripheral devices **1080**.

The components shown in FIG. **10** are depicted as being connected via a single bus **1090**. However, the components may be connected through one or more data transport means. For example, processor unit **1010** and main memory **1010** may be connected via a local microprocessor bus, and the mass storage device **1030**, peripheral device(s) **1080**, portable storage device **1040**, and display system **1070** may be connected via one or more input/output (I/O) buses.

Mass storage device **1030**, which may be implemented with a magnetic disk drive or an optical disk drive, is a non-volatile storage device for storing data and instructions for use by processor unit **1010**. Mass storage device **1030** can store the system software for implementing embodiments of the present invention for purposes of loading that software into main memory **1010**.

Portable storage device **1040** operates in conjunction with a portable non-volatile storage medium, such as a floppy disk, compact disk or Digital video disc, to input and output data and code to and from the computer system **1000** of FIG. **10**. The system software for implementing embodiments of the present invention may be stored on such a portable medium and input to the computer system **1000** via the portable storage device **1040**.

Input devices **1060** provide a portion of a user interface. Input devices **1060** may include an alpha-numeric keypad, such as a keyboard, for inputting alpha-numeric and other information, or a pointing device, such as a mouse, a trackball, stylus, or cursor direction keys. Additionally, the system **1000** as shown in FIG. **10** includes output devices **1050**. Examples of suitable output devices include speakers, printers, network interfaces, and monitors.

Display system **1070** may include a liquid crystal display (LCD) or other suitable display device. Display system **1070** receives textual and graphical information, and processes the information for output to the display device.

Peripherals **1080** may include any type of computer support device to add additional functionality to the computer system. For example, peripheral device(s) **1080** may include a modem or a router.

The components contained in the computer system **1000** of FIG. **10** are those typically found in computer systems that may be suitable for use with embodiments of the present invention and are intended to represent a broad category of such computer components that are well known in the art. Thus, the computer system **1000** of FIG. **10** can be a personal computer, hand held computing device, telephone, mobile computing device, workstation, server, minicomputer, mainframe computer, or any other computing device. The computer can also include different bus configurations, networked platforms, multi-processor platforms, etc. Various operating systems can be used including Unix, Linux, Windows, Macintosh OS, Palm OS, and other suitable operating systems.

The foregoing detailed description of the technology herein has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the technology to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. The described embodiments were chosen in order to best explain the principles of the technology and its practical application to thereby enable others skilled in the art to best utilize the technology in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the technology be defined by the claims appended hereto.

What is claimed is:

1. A method for monitoring a business transaction, comprising:

recording performance data for each of a plurality of methods of a network application, the performance data stored by an agent in a header of an execution thread that executes the method, the agent stored on a machine that executes the plurality of methods;

ignoring the performance data for one or more of the plurality of methods that satisfy a threshold;

generating a call graph from the performance data, the call graph indicating the root method of the business transaction and each method called as part of completion of the business transaction; and

storing the performance data for one or more of the plurality of methods having a root node that does not satisfy a condition.

2. The method of claim **1**, wherein the performance data includes a start time and an end time for execution of the method.

3. The method of claim **1**, wherein the condition includes a threshold for time of execution.

4. The method of claim **1**, wherein the condition includes calling an external Java Virtual Machine.

5. The method of claim **1**, wherein storing the data includes storing execution data and external call data.

6. The method of claim **1**, wherein the performance data is stored in an array within the execution thread header.

7. The method of claim **1**, further comprising:

building a call graph for a Java Virtual Machine; and

identifying methods within the call graph that do not satisfy the condition.

8. The method of claim **1**, further comprising:

qualifying the methods associated with the stored data;

storing a portion of the stored data based on the qualification of the methods.

9. The method of claim **1**, further comprising processing a stored hot spot data to generate a graphical representation of the methods.

10. The method of claim **1**, further comprising:

automatically identifying one of the plurality of methods executed as part of a business transaction as part of a learning process; and

recording performance data for each of a plurality of methods associated with the business transaction.

11. The method of claim **10**, wherein automatically identifying includes pre-loading previously stored methods associated with the business transaction.

12. The method of claim **11**, further comprising ending the learning process based on a number of times that automatically identifying is performed.

13. The method of claim **12**, further comprising re-starting the learning process after a period of time.

14. A non-transitory computer-readable storage medium having embodied thereon a program, the program being executable by a processor to perform a method for monitoring a transaction, the method comprising

recording performance data for each of a plurality of methods of a network application, the performance data stored by an agent in a header of an execution thread that executes the method, the agent stored on a machine that executes the plurality of methods;

ignoring the performance data for one or more of the plurality of methods that satisfy a threshold;

generating a call graph from the performance data, the call graph indicating the root method of the business transaction and each method called as part of completion of the business transaction; and

storing the performance data for one or more of the plurality of methods having a root node that does not satisfy a condition.

15. The non-transitory computer-readable storage medium of claim **14**, wherein the performance data includes a start time and an end time for execution of the method.

16. The non-transitory computer-readable storage medium of claim **14**, wherein the condition includes a threshold for time of execution.

17. The non-transitory computer-readable storage medium of claim **14**, wherein the condition includes calling an external Java Virtual Machine.

18. The non-transitory computer-readable storage medium of claim **14**, wherein storing the data includes storing execution data and external call data.

19. The non-transitory computer-readable storage medium of claim **14**, wherein the performance data is stored in an array within the execution thread header.

20. The non-transitory computer-readable storage medium of claim **14**, the method further comprising:

building a call graph for a Java Virtual Machine; and

identifying methods within the call graph that do not satisfy the condition.

21. The non-transitory computer-readable storage medium of claim **14**, the method further comprising:

qualifying the methods associated with the stored data;

storing a portion of the stored data based on the qualification of the methods.

22. The non-transitory computer-readable storage medium of claim **14**, the method further comprising processing a stored hot spot data to generate a graphical representation of the methods.

23. The non-transitory computer-readable storage medium of claim **14**, the method further comprising:

automatically identifying one of the plurality of methods executed as part of a business transaction as part of a learning process; and

recording performance data for each of a plurality of methods associated with the business transaction.

24. The non-transitory computer-readable storage medium of claim **23**, wherein automatically identifying includes preloading previously stored methods associated with the business transaction.

25. The non-transitory computer-readable storage medium of claim **24**, the method further comprising ending the learning process based on a number of times that automatically identifying is performed.

26. The non-transitory computer-readable storage medium of claim **25**, the method further comprising re-starting the learning process after a period of time.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,311,598 B1
APPLICATION NO. : 13/365171
DATED : April 12, 2016
INVENTOR(S) : Jyoti Bansal et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, the last name of inventor Bhaskar Sankara should be spelled "Sunkara,".

Signed and Sealed this
Eighth Day of November, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office